THE

CHEMISTRY OF THE MINE;

A COURSE OF

THREE LECTURES,

DELIVERED TO THE MEMBERS OF THE

SOUTH STAFFORDSHIRE & EAST WORCESTERSHIRE

INSTITUTE OF MINING ENGINEERS,

BY

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LECTURE I.

THE Chemistry of the Coal Mine, viewed in its simplest and most restricted aspect, is that of *carbon* and *hydrogen* on the one hand, and of atmospheric *oxygen* on the other. The compound resulting from the union of the elements carbon and hydrogen, is too well known to miners, under the name of Fire-damp; which in the ordinary acceptation of the term is a combustible substance, or has the power of burning; while the Atmosphere is the medium in which the gas burns, or, as it is sometimes expressed, is the "supporter" of the combustion.

In order to obtain a clear and intelligent view of our subject, it is necessary that we make ourselves, in the first place, acquainted with the chemical and physical properties of all the elements concerned; and I propose, therefore, before entering upon the subject proper of Fire-damp, to consider, in the first lecture, the properties of the constituents of the Atmosphere, together with certain facts and phenomena immediately connected with this branch of the subject.

The Atmosphere is the medium of all ordinary combustions and explosions; it is the globe of gas (*atmos*, vapour, and *sphaira*, a sphere) which entirely surrounds our earth, similarly to the manner in which the rind surrounds the central part

of the orange. It surrounds every object on the earth, and penetrates into the interior of porous bodies. When at rest, we are scarcely cognizant of its existence; it does not then make itself felt, nor in any way perceived, more particularly as it is invisible, inodorous, and tasteless. But when it is in motion, its existence becomes at once evident, either in the draught, the gentle breeze, the gale, or the tornado, in which it is not only felt, but it is also heard, and the effects of its power are of a striking, and even alarmingly destructive character. Moderated in the form of an ordinary wind, it is usefully employed in turning the windmill or propelling the ship, but in the height of its power it becomes an agent of destruction and death. The atmosphere continually envelops the earth, because, being material, it necessarily has weight, and is therefore attracted to it, so that as the earth revolves, the atmosphere revolves with it, like other ponderable masses lying upon the surface. If this were not so, everything would be swept off the face of the earth, for as the latter revolves on its own axis at the rate of 1,000 miles an hour at the equator, it follows of necessity, that if the air were stationary instead of moving with the revolving earth, there would be at the equator a constant wind blowing with irresistible force, and virtually travelling at the same rate.

That the atmosphere is material is easily proved by the fact that it occupies space to the exclusion of other matter. Thus, an inverted tumbler may be immersed in water without becoming wet in its interior, water cannot be poured into a bottle through a tightly fitting funnel, neither can a well-fitting piston be forced to the bottom of a closed cylinder, because in all these cases the vessels are occupied by material air, and if they are to be filled with any other matter, the air must be first displaced. *(These facts were experimentally illustrated).*

The atmosphere, then, being material, it must have weight, and having weight it must exert pressure ; these facts admit of proof in a great variety of ways. The syringe and common pump both act in consequence of the pressure of the air, and they admirably well illustrate the point.

A wineglass perfectly filled with water and covered with paper may be inverted without spilling its contents, because the pressure of the Atmosphere on the under side of the paper is greater than that of the small column of water on the upper side. *(Experiment.)*

The Barometer (commonly called a weather-glass) is an instrument which is used for measuring the amount of the atmosphere's pressure, which varies at different times, and this variation has a close connection with meteorological phenomena, as well as with the condition of coal mines. *(The Barometer was here exhibited, and its construction and action explained).*

It was Galileo who first pointed out that the reason water could not be raised to a greater height than about 32 feet in a common pump, is, that the pressure of the whole atmosphere is equal to the weight of a column of water only about 32 feet high ; and Torricelli, his pupil, confirmed the correctness of this view by showing that the mercurial column of 30 inches (or 760 millimètres) high, is of just the same weight as the column of water 32 feet high, so that the columns of water and of mercury respectively, balance a column of atmospheric air, because they are all three of the same weight. If wine were introduced into a barometer tube it would, owing to its being lighter than water, stand at a height of 34 or 35 feet.

The pressure exerted by the atmosphere at the level of the sea is then equal to the weight of the column of mercury 760 millimètres (about 30 inches) high, and is easily estimated by

weighing the column of mercury. Such a column of mercury 760 millimètres high and one centimètre square, is found to weigh 1·033 kilogrammes; the *pressure* of such a column on a square centimètre is therefore the same, and as it is exactly balanced by the pressure of the atmosphere, the pressure of the latter and its weight must also be the same as those of the column of mercury, viz.: 1·033 kilog. on the square centimètre, or about 15 pounds on the square inch.

Such being the weight pressing on a square inch, that on the whole surface of the earth must be enormous, and the earth's area being known, the pressure of the atmosphere upon it is computed at five thousand billions of tons. In like manner, the amount of pressure on any object can be readily calculated by taking its area. It has thus been found that the superficial area of the human body is such, that a middle-sized man sustains constantly a weight of about 14 tons.

This seems at first sight highly improbable—it strikes one that such a weight could neither be borne and allow of movement, nor be imposed without instantaneous destruction; but it must be kept in mind that the pressure is equal on all sides, within, and without; and it is this universality of pressure which holds the body harmless. Indeed, the pressure is proved to be beneficial, for it is not at all uncommon for mountaineers and aëronauts to suffer from spitting of blood caused by a diminution of this pressure on the lungs, leading to rupture of some of their vessels; for as we ascend from the level of the sea to more elevated positions, a portion of the atmosphere is left below, and that above necessarily has less weight, so that the barometer falls more and more the higher we ascend, proving the diminution of weight so exactly, that by means of this instrument the heights of mountains and other elevated positions can be ascertained. Thus, the mercurial column, which at the level of the sea has a height

of 760 millimètres, at Potosi, 13,220 feet above the sea level, has a height of only 471 millimètres.

Another proof of the weight of the air is found in the fact that a flask when exhausted of air weighs less than when full. It has thus been experimentally found that a litre of air at 0° Centigrade, and 760 millimètres pressure weighs 1·2932 grammes.

The atmosphere being a mixture of gases, is expansible by heat like any simple gas, as may be readily shown by the simple experiment of heating an inverted flask with its mouth in water, when the air will be seen to bubble through the liquid, proving that it has expanded and can no longer be all contained in the flask. *(Experiment).*

I shall have more to say upon this subject in one of my future lectures, and therefore content myself with simply referring cursorily to it in this place.

The *chemical* constitution of the atmosphere now demands our attention, and I need hardly say that although it was regarded as an element by the ancients, it is a complex mixture of gases. This mixture consists of oxygen and nitrogen principally, the former being present in the proportion of one-fifth, the latter constituting the remaining four-fifths. There are besides these, small quantities of other gases and vapours, some of which are constant, others occasional or variable. Those which are small in quantity, but constant, and therefore of high importance, are carbonic acid, ammonia, organic matter, and aqueous vapour; those of less importance include nitric and sulphurous acids, and certain hydro-carbons.

Of these numerous constituents of air, however, I shall have to direct your attention only to the first three, viz., oxygen, nitrogen, and carbonic gas; and even of these the first alone will claim much of our attention and study in the present lecture.

That the proportions of oxygen and nitrogen in the air are 1 to 4 is readily illustrated by burning a substance in a confined portion of air. All the oxygen will be removed, and we shall observe that when the residual gas has cooled, it measures four-fifths of its original volume, the one-fifth removed being that which has combined with the combustible; so that in this experiment we have a rough analysis of atmospheric air. *(The oxygen was removed by burning phosphorus in a confined portion of air).* With respect to the nature and properties of the remaining gas, I shall say more presently.

That the atmosphere is a *mixture* of gases only, and not a chemical compound, is evident from a number of facts and considerations. The proportions of the mixed gases are not absolutely invariable, which they would be if it were a chemical compound. They are not present in the proportion of their combining weights; nor do their volumes bear that simple relation to each other which is observed in the combination of gases. When the gases are mixed in the proportions in which they exist in the air, none of those phenomena occur which attend chemical combination, such as elevation of temperature, diminution of volume, or other change of properties. When the atmosphere is in contact with water, its gases dissolve not in their proper proportion, but according to their respective solubilities, oxygen being the more soluble of the two; so that air boiled out of water, instead of being composed of one-fifth oxygen and four-fifths nitrogen, contains one part of the former to only 1·87 of the latter. Now any compound gas is not affected in this way by solution, but is restored with its component elements in the same proportion as that in which they existed before solution.

Oxygen was discovered by Dr. Priestley, at Birmingham, in 1774, and it is remarkable that Scheele, in Sweden, also dis-

covered the gas in 1775, without having any knowledge of its discovery by Priestley in the previous year.

It is interesting in very many particulars. In the first place, it is the most abundant of all the elements, for it is calculated to constitute not less than three-fourths of the globe. This is not difficult to understand when we know that it forms about half of the three most widely-spread constituents of the earth, viz., silica, alumina, and chalk, and in fact forms part of nearly all rocks and minerals; that it constitutes more than one-fifth of the atmosphere, and eight-ninths of all water. It exists largely in the animal and vegetable kingdoms, being an essential constituent of every plant and animal.

The gas may be prepared in a great variety of ways, but the most interesting and perhaps the most instructive is that by which Priestley prepared and discovered it on the 1st August, 1774, viz., by heating oxide of mercury, commonly called red precipitate; this he did, not by a lamp, but, by causing the rays of the sun to converge upon the oxide through a burning glass, the oxide being placed in a tube filled with mercury, upon which the oxide floated. He found that the heat caused decomposition, with liberation of a gas which was not absorbed by water, and which brilliantly supported the combustion of a taper. He called the gas "dephlogisticated air," in accordance with Stahl's phlogistic theory. But over and above the interest attached to this mode of obtaining oxygen, it is remarkably instructive as illustrating analytically the composition of oxides; for in this case we have a metallic oxide, which yields both the metal and the oxygen in a condition to admit of examination. Let us see this.

But the sun having set, and a gas burner being in every way more convenient as a source of heat, we will avail ourselves of it for effecting the decomposition required, instead of the original method employed by Priestley. *(Mercury*

oxide was heated, and both the metallic mercury and the oxygen obtained separately).

Interesting and instructive, however, as is this method of obtaining oxygen, it is neither convenient nor economical, and therefore the gas is usually obtained by some cheaper and readier method. The material most commonly used for its production is potassium chlorate, either alone or mixed with some other substance to assist in its more equal and ready decomposition; this salt consists of potassium, chlorine, and oxygen, the last element of which is all evolved by heat, the two former remaining in the retort in the form of potassium chloride. I will prepare a little of the gas by this method. And now having obtained it, the first feature that attracts attention is its change of state. In both the mercuric oxide and the potassium chlorate it existed in the *solid* state, here we have it in the gaseous form, whereas in fluid water we find it in a liquid state, combined with hydrogen. The gas, however, by itself has never been either liquefied or solidified by any amount of pressure or cold which has been brought to bear upon it; in which respects it differs from many simple and compound gases, chlorine and carbonic gas, for example, the former of which has been liquefied, and the latter, with several other compound gases, not only liquefied, but also solidified, by that great and original experimenter, Faraday.

The physical properties of oxygen may be described in a few words. It is invisible, colourless, tasteless, and inodorous. It is permanent—that is, it has never been liquefied; in this respect it is like hydrogen and nitrogen. It is heavier than air, its specific gravity being 16, while that of air is only 14·4, taking hydrogen as the standard; taking air as unity, its specific gravity is 1·1056. One litre of gas weighs 1·4298 grammes; 100 cubic inches weigh 34·29 grains. It is soluble in water to the extent of 3 volumes in 100, which is not a

large quantity, but still sufficient to maintain aquatic life by serving for the respiration of aquatic animals, just as the same gas in the atmosphere supports the respiration of animals occupying the surface of the earth. Some faint conception of its importance in this relation, as well as of its total amount in the world, may be formed from the fact that for the respiration of human beings alone, it is calculated that one thousand millions of pounds are required in a single day, for that of animals twice as much, whilst another thousand millions is required for the processes of combustion and fermentation, making four thousand millions of pounds; and this total amount must be doubled, to include the quantity necessary for the continuous, unceasing processes of decay. Reduced to tons, this enormous number of pounds is utterly beyond our mental grasp, for it is equal to 7,142,847 tons per day. Oxygen is more powerfully attracted by the magnet than all other gases.

I must now hasten to illustrate the great energy which oxygen displays in its union with the other elements, with all of which, except one, fluorine, it is known to enter into combination. I may remark first, however, that the *presence* of oxygen may be shown in several ways; one excellent test is nitric oxide, a colourless, neutral, insoluble gas, which, on coming into contact with oxygen, instantly combines with it, forming a red gas, endowed with acid properties and soluble in water. Another remarkably sensitive test is pyrogallate of potassium, forming a colourless solution in water, but rapidly absorbing oxygen on coming into contact with it, at the same time changing to an intensely dark, brown-coloured liquid.

Let us now examine the way in which this all-important element exerts its affinities towards other elements, availing ourselves of the favouring influence exerted by an elevation of temperature. If I take a wooden spill, light it, and blow

it out, leaving a spark at the end of it, and then immerse it in a jar of the gas, it will instantly be relighted and will burn with great rapidity and energy. *(Experiment).*

On treating a wax taper in the same way, leaving a spark on the wick, there is a similar phenomenon, with this addition, that a sharp report or explosion attends the inflammation of the combustible. *(Experiment).*

The results of the combustion in both the above cases being invisible, many persons would say that the portions of wood and candle burnt were destroyed, and such a view would no doubt in former times be taken by the disciples of Stahl, who would assume that *phlogiston* had been given out during the combustion, and hence the substance had become lighter. Presently, however, I shall show you instances of combustion in oxygen where the products of that combustion are solid, and where if we could spare the time to weigh them, we should find they were heavier than the combustibles burnt.

I will now introduce a piece of burning sulphur into a jar of the gas, and you see how much more vividly it burns than in air, and with how much more intense a colour; while if we introduce a little water and shake it up with the gas so as to dissolve it, we shall find that we have an acid compound formed as the result of the union of the two elements. This compound is called sulphurous acid, or sulphurous dioxide.

We have already seen the energy of combustion in an atmosphere of pure oxygen, as exemplified in the burning of the spill, the paper, and the sulphur, in all of which examples the products of combustion were partly or entirely *acid*, and they were also gaseous. I now wish to direct your attention to the combustion of a substance which is ordinarily regarded as anything but combustible—I mean the metal iron; and certainly under ordinary circumstances of temperature and atmospheric contact, iron does not burn, although it does

oxidise or rust. If, however, we raise its temperature and insert it into an atmosphere of pure oxygen, we shall see that it is strictly a combustible substance, and that its combustion is very vivid and brilliant, and the heat is so intense as to fuse the oxide formed. *(A steel spring was burnt in oxygen).*

This experiment, however, possesses other points of interest, for it was instituted by Priestley himself, the discoverer of the gas; and moreover, it had much to do with the refutation of the phlogistic theory, according to which bodies are lighter after burning. If we were to collect and weigh the product of the combustion, which in this experiment is *solid*, we should find that it is heavier than the iron which has burnt; the additional weight being that of the oxygen, which has combined with the metal.

The examples of combustion in oxygen which I have already adduced and illustrated, are all energetic and brilliant, although the substances burnt were merely common combustibles and iron; if, however, we take a piece of phosphorus, a substance particularly prone to take fire, and burning even in common air with great energy and dazzling light, and introduce that, ignited, into a jar of oxygen, we have one of the most energetic acts of chemical union known, and a brilliancy of luminous effect insupportable by the eye. *(Experiment.)*

The intense luminosity of this combustion is one of great general interest, as illustrating the cause of luminosity of flames in general; but as time will not permit me to enlarge upon the subject at this stage, I must reserve it for our next lecture, where the study of the element carbon will give us an equally good and appropriate opportunity of discussing and illustrating the point.

I have only to direct your attention to the fact that the result of the combustion of phosphorus is an acid compound, phosphoric acid; just as in the burning of sulphur we had an

acid oxide left. Lavoisier having observed that the product of combustion was frequently acid, came to regard oxygen as the acidifying principle in nature, and hence named the gas oxygen, from the two Greek words, *oxus*, acid; and *gennao*, I produce. We know now, however, that this view is no longer tenable; as there are many compounds, of an intensely acid character, which contain no oxygen.

There used to be laid great stress on the distinction between bodies which are "combustibles," and those media in which they burn, and which were called, and are often so called even now, "supporters of combustion." The distinction is entirely founded on a misconception, and has given way to more correct knowledge. It is easy, however, to see how the error occurred. If a light be applied to a jet of hydrogen, the gas burns by uniting with the oxygen of the air; if we now apply a light to a jet of oxygen it will not burn, simply because it has nothing to combine with, for bodies cannot combine with themselves in a chemical sense; but if we reverse the conditions of the first experiment, and apply flame to a jet of oxygen in an atmosphere of hydrogen, we shall see that the former is as much a combustible as the latter. The combustion is really the union of the two gases where they are in contact; when a jet of hydrogen is admitted into oxygen, the latter gas surrounds the jet, union can only take place around it, and the hydrogen alone *appears* to burn. In the same way, when a jet of oxygen is admitted into an atmosphere of hydrogen, the latter gas surrounds the jet of oxygen, and combustion can only take place where they are in contact, or round the exterior of the jet, so that in this case there is an apparent reversal of the experiment, and it is the so-called incombustible oxygen which *appears* to burn; in reality, however, the one burns no more than the other, the act of union being one of mutual chemical attraction, the heat and light

evolved, being merely phenomena attending the combination. *(These facts were illustrated by burning a jet of hydrogen in oxygen, and then a jet of oxygen in hydrogen).*

By combustion, then, is understood chemical action of such intense energy as to be accompanied with heat and light. It must not be confounded with ignition or incandescence, which is nothing more than the making of a body hot by external means, and without any change in its chemical constitution: in combustion, the heat and light are caused by chemical change, in ignition no such chemical change takes place. We have an example of combustion in the burning, without external aid, of a lump of coal; we have an example of ignition, or incandescence, in a lump of clay made red or white-hot in a furnace.

The cause of the heat and light attending combustion has from early times occupied the attention and excited the speculation of philosophers. Beecher and Stahl were the first to arrange the facts and construct a hypothesis upon them. Stahl's hypothesis was that all combustible bodies contained a something which he called "phlogiston" (burning principle—*phlego*, I burn); that it was the escape of this principle from the burning substance which produced the light and heat, and constituted combustion, and that the restoration of it to the body burnt, re-endowed it with combustibility. Thus, when a piece of charcoal burns, yielding carbonic gas, it is assumed in this phlogistic theory that phlogiston escapes, and in the act of escaping produces heat and light, so that the original charcoal or carbon is to be regarded as a compound of phlogiston and the carbonic gas which has resulted from the combustion.

The believers in the phlogistic theory knew nothing of the part played by the oxygen of the air in combustion, nor did they attribute the proper value to the fact, of which they

were latterly aware, that bodies become heavier when burnt; for if their theory were true, the loss of anything, phlogiston not excepted, should make the body losing it, lighter; whereas when any substance is burnt the reverse is the case—it becomes heavier. The carbonic gas, for instance, is heavier than the carbon producing it in the proportion of 44 to 12, or, in other words, 12 parts of carbon, in burning and giving out heat and light, yield 44 parts by weight of carbonic gas.

The discovery of oxygen, by Priestley, the method of which Priestley himself showed to Lavoisier, and the experiments of the latter distinguished man with it, totally disproved the phlogistic theory, and showed that it was diametrically opposed to the truth. Lavoisier in availing himself, more than had ever before been done, of the balance, demonstrated that bodies, in burning, always become heavier; that instead of losing phlogiston, or anything else, they acquired a certain amount of oxygen, and became to that extent heavier; the resulting weight being always the sum of the weights of the combustible, and the oxygen with which in burning it had combined.

This theory, named the "anti-phlogistic," failed for a long time to convince the adherents of the phlogistic hypothesis, who to maintain their views, ingeniously, though speciously, assumed that phlogiston was the principle of "levity," so that a body in losing it became heavier; in other words, its gravity was increased. This, however, was merely an assumption and was incapable of proof, whereas facts were being continually established which carried convincing proof of the truth of the anti-phlogistic theory, until at last the old view ceased altogether to be maintained, and gave way to the new one which is now in universal acceptance.

Lavoisier suggested that the light and heat of combustion are due to the latent heat of the oxygen, in the act of

combining, becoming sensible. It is, however, well known that the latent heat of bodies is altogether insufficient to produce the amount of sensible heat developed during the process of combustion.

Berzelius attributed the heat and light to the union of the two opposite kinds of electricity which exist in two bodies before combination. This hypothesis, however, is not satisfactory. The one most in favour is that of Davy, a name highly distinguished in connection with combustion in general, and with the Chemistry of the Mine in particular. Davy regarded *motion* as the cause of heat and light, the mode of their production being analogous to that of light, viz., that as light is believed to be produced by the vibration or undulation of particles of a subtle fluid called *ether*, which is assumed to occupy all space, so the light and heat of combustion are evolved by an analogous motion of certain particles. On this view, the great heat and light produced by friction, and in chemical combinations of an energetic and violent kind, are explicable and intelligible. It is a matter of no importance whether the chemical force is exerted in the direction of combination or of decomposition, whether in the burning of a combustible in which we have the former action, or in the explosion of nitrogen chloride in which we have the latter one. The heat and the light thus appear to be the result simply of rapid and violent motion, and of motion only.

The temperature at which different substances combine with oxygen to take fire widely varies. Phosphorus undergoes slow combustion at 25° C., but not rapid combustion until the temperature rises to 60° C., charcoal burns slowly below a red heat, sulphur at about 285° C. (550° F.) *(Differences of igniting points shewn.)*

Most bodies require to be heated to redness before they will burn in oxygen, while there are some such as phosphuretted

hydrogen, together with zinc-methyl, cacodyl, and some other organic compounds, which inflame at the ordinary temperature on coming into contact with the air. I can show you the spontaneous inflammability of phosphuretted hydrogen. This gas is seen to flicker about boggy, wet lands, and is called "Ignis Fatuus," "Will o' the Wisp," and "Jack o' Lantern." It is produced by the decay of animal and possibly of vegetable matters; decaying fish evolve gases having the odour of phosphuretted hydrogen, to which in some measure no doubt the smell of stinking fish is due; and it is well known that fish in a state of decomposition are luminous in the dark, no doubt, also, from the slow combustion of this phosphoric compound.

Other substances combine together at common temperatures without the intervention of oxygen; of these, phosphorus and chlorine, phosphorus and bromine afford good examples. The results of their combination, attended with flame, are respectively chloride of phosphorus, and bromide of phosphorus, in which compounds oxygen finds no place; the heat and light given out here, are due entirely to spontaneous combustion. *(Phosphorus and bromine were shewn to combine with production of heat and light.*

A certain amount of heat, however, is necessary even for the combination of these elements, for if they are brought together in a vessel cooled with ice, combination does not take place. We see here, then, that combustion is not necessarily connected with our atmosphere, but is nothing more than energetic chemical combination accompanied with the evolution of heat and light.

Certain substances possess the remarkable power of determining the union of oxygen with combustibles, foremost among which is platinum; if a clean surface of this metal be brought into contact with an inflammable mixture it will

determine combination. In some cases a sheet of platinum, or a coil of platinum wire at the ordinary temperature, is sufficient for this purpose; in other cases it is necessary that the platinum be finely divided, in the form either of spongy platinum or of platinum black, which is the metal in a state of extremely minute division.

By elevating the temperature of the platinum, however, the property referred to is more readily exhibited, and I can, by gently warming this clean coil of platinum wire, effect the lighting of a gas jet. *(A jet of gas was lighted by means of a warm coil of platinum.)*

In Dobereiner's instantaneous lamp, spongy platinum is used without any previous elevation of temperature; when a jet of hydrogen is made to play upon it, it determines its union with the oxygen of the air on its surface and within its pores, which is followed by an elevation of temperature sufficient to raise the metal to an intensely red heat, when the jet of the hydrogen becomes inflamed, and continues to burn as long as the supply of hydrogen is maintained.

This remarkable property is not confined to platinum; it is possessed, more or less, by a great number of other solid substances, many metals, pumice stone, glass, and charcoal.

Minute division greatly disposes bodies to take fire even without any assistance from external elevation of temperature; this is well seen in metals in what is called the pyrophoric condition. A lump of lead is only very slowly oxidised by exposure to the air, but when very finely divided it becomes *pyrophoric* (pur, fire, and phero, I bear), and takes fire immediately on coming into contact with the atmosphere. The same is true of metallic iron in a state of minute division. *(Lead and iron in the pyrophoric condition were here exhibited, taking fire immediately on exposure to the oxygen of the air.)*

There are two explanations of these striking and highly interesting phenomena. One is that the finely divided metal, made so by reduction by hydrogen, retains that gas, and that when exposed to the air oxygen is absorbed and combines with the hydrogen, developing, in doing so, sufficient heat to determine combustion of the metal as well as of itself. The other explanation is, that the oxygen of the air is rapidly absorbed into the pores of the finely divided metal or substance, that it is at the same time condensed, and that the condensation, as in all other cases, is attended with the development of heat, sufficient, in these instances, to cause the solid to take fire by uniting at last energetically with the oxygen.

These cases may be regarded as examples of true spontaneous combustion, and they are not confined to metals, but extend to other porous matters—to hayricks, greasy tow and cotton-waste, butter rags, oiled silk, charcoal, and, what is particularly interesting to us, small coal, which you well know is prone to spontaneous combustion, entailing great danger and pecuniary loss. The pyrophorus already exhibited shews how fine division affects these phenomena, and we may look upon the finely divided coal as being carbon in a rough, pyrophoric condition.

The effect of fine division on combustion, is also well seen in the case of phosphorus; a lump of phosphorus may remain for days or weeks without igniting, while in a state of minute division it bursts into flame immediately. The lump of phosphorus may be looked upon as a harmless lump of coal, while in the finely divided combustible we have the more active analogue of *small* coal. *(Minutely divided phosphorus was here shewn to take fire spontaneously, on exposure to the air.)*

In all these cases, whether of finely divided metals or of organic substances, the rationale of the action is the same:

there is absorption of oxygen—by which heat is generated, this raises still more the affinity of the combustible for the oxygen, by which heat is developed still more rapidly; with continued increase of heat the process becomes quickened, favoured, in some of the instances, by the non-conducting nature of the substance, absence of draughts or currents of air, and of other cooling influences, until at last there is sufficient elevation of temperature to determine vivid combustion.

Nitrogen, the other principal ingredient of air as regards its bulk, will not require a very lengthened notice. It was discovered by Dr. Rutherford in, and derived its name from, "nitre," of which it is one of the constituents. It is a colourless, tasteless gas, without odour, and is generally described, in short, as a highly negative element. It does not burn, it does not support ordinary combustion, it does not support animal life, although it is not poisonous; it is not very soluble in water, it is not so heavy as air, being only 14 times as heavy as hydrogen, whereas air is 14·4 times as heavy; or, air being taken as the standard of specific gravity or as unity, the specific gravity of nitrogen is 0·972. I have said that nitrogen will not support life, and that it is not poisonous; this may appear to you a little paradoxical, but it becomes plain and consistent when we bear in mind that oxygen is the *only* substance that will support the respiration of animals, and that therefore its removal and substitution by any other gas will lead to death, although the gas substituted, as in the case of nitrogen, be not poisonous.

That nitrogen is not poisonous is clear from the circumstance that we are continually breathing it in large quantities.

Carbonic gas forms comparatively a very small portion of the atmosphere, averaging about four measures in 10,000 of air. It varies a little in the same places at different times, and it varies in different places; it undergoes variation, also,

between night and day. It exists in larger quantities in the vicinity of volcanoes, and in large towns, and more particularly in crowded and confined places, houses, public buildings, mines, &c., owing to inefficient ventilation. I shall have to speak more fully on this point in my last lecture, but I would observe here, that though the relative quantity of this gas is small, its absolute quantity is enormously great. It is highly poisonous when not highly diluted, and in reference to this fact it is worthy of note that the animal and vegetable kingdoms hold a beneficent and beautiful relation to each other, it being exhaled by the animal, to which it is poisonous, and absorbed by the plant, for which it is food; so that the existence of vegetation is absolutely indispensable, in order to maintain the atmosphere sufficiently pure for the respiration of animals.

The sources of atmospheric carbonic acid are very numerous, viz., the respiration of animals, combustion, fermentation, decay, and volcanic emanations. The gas itself is very heavy, viz., 22 times as heavy as hydrogen, and $1\frac{1}{2}$ times as heavy as air. It is prevented gravitating, however, and destroying the whole animal creation, by a beautiful law of diffusion and circulation, which regulates the condition of gaseous matter; and which I shall have to refer to, more in detail, in my next lecture.

It is easy to show that carbonic acid exists in the air, for if a clear solution of lime (lime water) is exposed for a time it becomes turbid and milky from the formation of chalk, which is carbonate of lime. To give an idea, however, of how little of the gas is contained in the air, I will draw several gallons of air through a little lime water, and it will be seen how small an amount of carbonate of lime is formed, hardly enough to occasion a distinct milkiness. *(The experiment was performed).*

I have now passed in review the physical and chemical characters of the atmosphere and its principal constituents, at the risk, perhaps, of being somewhat tedious and apparently discursive; it has, neverthless, been my sole object to bring before you such an array of facts and theories, in this my first lecture, as shall enable you the more profitably to avail yourselves of the truths which you will have to study in the two following lectures, and which will, I trust, prove not only of passing interest, but of lasting service to you, in the pursuit of your important and responsible calling.



LECTURE II.

This evening, gentlemen, I propose drawing your attention to the chemistry of the elements which enter into the constitution of Coal and Fire Damp. The last lecture was devoted largely to a consideration of the atmosphere, as the medium in which combustible bodies burn. We will now apply ourselves to the study of the elements in our particular field of enquiry, which have the power of burning in that medium: these are *Carbon*, *Hydrogen*, and *Sulphur*.

Carbon is an element of very great interest, both as to its physical and chemical properties, and the same may be said of its numerous compounds. It must have been known from the earliest times. It is extremely abundant, and occurs in a great variety of forms, which, however, may be reduced to three allotropic modifications, *i.e.*,varieties of the *same chemical* element, distinguished by *difference* of *physical* condition. These three allotropic forms are: 1st, the diamond; 2nd, plumbago; 3rd, charcoal, from whatever source derived. Chemically, these three bodies are identical, for when they are heated in oxygen they each lose their solid form and become converted into invisible carbonic acid gas. Physically, they differ in transparency, colour, hardness, weight, conducting

power, and in a variety of other ways, though they are all solid, tasteless, inodorous, infusible, and fixed at all temperatures, except that of a very powerful galvanic battery, by which carbon is said to be both melted and converted into vapour; but this is not quite certain. Carbon is an ingredient of every animal and vegetable, and though it is sometimes called a mineral, owing to its occurrence in large quantities, both free and in combination, in the crust of the earth, yet it must be considered the characteristic component of animal and vegetable structure; and this has given rise to the latest definition of the chemistry of organised bodies and organic substances, viz., that it is the "chemistry of the compounds of carbon." But besides existing free in the three elementary bodies above mentioned, carbon occurs in enormous quantity in combination, in the form of carbonic acid gas, in the atmosphere, and in many minerals existing in great abundance, such as chalk, limestone, and marble, besides coral, shells, pearls, &c.

Let us briefly glance at the properties of the different varieties of carbon—1. *The Diamond.* It is transparent, crystalline, and the hardest of known bodies, so that it can be polished only by its own powder, or the process of "diamond cut diamond," and it cuts the hardest glass readily. It is a bad conductor of electricity, and when placed in the arc of the electric light it loses its transparency, swells up, and becomes a black, opaque mass of charcoal. Owing to its density it is very difficult to burn, even in pure oxygen, in which it must be heated by either the electric discharge, or by the intensely hot oxyhydrogen flame, before it will enter into combustion.

Plumbago, or graphite, is opaque, and though crystalline, the form of the crystal differs entirely from that of the diamond, which assumes forms derived from the cube, while graphite crystallises in six-sided plates, having no rela-

tion to the cube. It occurs in the primitive and the earliest sedimentary rocks, the best in the world being found at Borrowdale, in Cumberland. It is black, sometimes called blacklead, from its colour and appearance, but improperly, as it contains no lead, but consists almost entirely of carbon. Unlike the diamond, it is soft and greasy to the touch, and marks paper like lead. Owing to its close texture it is extremely difficult to burn, and is therefore very valuable as a coating to stoves, which it protects from the rusting action of the air; and as an ingredient of certain kinds of crucibles which have to support a great heat. Its other uses are for making pencils, for coating grains of gunpowder, for conducting electricity over the faces of electrotype moulds, and as a lubricant for some kinds of machinery, in which it diminishes the friction, particularly of wooden bearings; so that, if not so beautiful as the diamond, it is far more useful.

The third form of carbon is *Charcoal*, of which there are several varieties, viz., wood charcoal, coke, animal charcoal, lamp black, anthracite, and we may include the other varieties of coal, as consisting principally of carbon.

It will be useful to us to consider here a few facts in connection with the production of wood charcoal, the principles involved in it appertaining equally to that of other kinds of charcoal, including the natural formation of coal. Wood is composed principally of carbon, with hydrogen and oxygen; if it be heated with access of air, it burns away by uniting with the oxygen of the air, and forming carbonic acid gas and water, which may be collected and examined.

If, however, it be heated in a nearly close vessel, so as to exclude the atmospheric oxygen, it does not burn away; it undergoes decomposition, in which its constituent elements re-arrange themselves, the resulting compounds being removed by the heat in consequence of their volatility, and

consisting principally of water, naphtha, tar, and gaseous compounds of carbon and hydrogen, while there remains in the retort a black infusible coal-like mass, called charcoal, and consisting of nearly pure carbon, associated, however, with a little hydrogen, still less nitrogen, and the mineral constituents or ashes of the wood. We shall see presently that a similar change takes place in the formation of coal, and such a process as this, where a complex substance breaks up under the influence of heat into simpler and more stable compounds, is called "destructive distillation." *(The destructive distillation of wood was here performed, water, naphtha, &c., collected, and the gaseous products burned at a jet).*

The charcoal left here is very porous, which is owing to the fact that it does not fuse together, it being infusible; and it is this porosity which enables charcoal to absorb various matters, such as gases, vapours, colouring matters, bitter principles, &c. So great is this power of absorption, that dense charcoal, freshly burned, will absorb upwards of one hundred times its volume of ammonia gas, and less of other gases, apparently in proportion to their power of being condensed to liquids. This brings us back to the question which I discussed at some length in my last lecture, when I showed how porosity and minuteness of division led to the absorption and condensation of gases, and consequent development of heat, as shown in the spontaneous combustion of various substances, including small coal. The experimental illustration of the absorption of gases by charcoal requires too much time and preparation to allow of my exhibiting it here, but I can show you how colours are absorbed, and, by analogy, you will readily understand how gases are acted upon in a similar manner. *(Blue litmus was treated with charcoal, and shown to be deprived of all colour).*

You observe that on filtering this mixture of charcoal and

litmus, the liquid runs through perfectly colourless. This property is taken advantage of in Chemistry, and in the Arts, for the removal of colouring and other matters from chemical preparations, from sugar, distilled spirits, &c.

All the varieties of carbon are remarkable for their fixed character; they are entirely insoluble, they are infusible, and, out of contact of the air, may be heated to the highest temperature of the hottest furnaces without change; neither do they undergo change in contact with the air or oxygen, unless their temperature be raised.

Owing to the resistance of carbon to oxidation, it is common to char the ends of poles before placing them in the ground, by which the wood beneath is protected from even the combined action of air and moisture.

Before taking leave of carbon as an element, and passing on to its compounds, I wish to say a few words on the origin and formation of coal, which will be readily intelligible after what I have said about the changes which take place in wood when it is subjected to destructive distillation.

Coal occurs in immense beds, of such extent that it has given the name to a geological division of the earth's crust, called the "carboniferous formation." This term carboniferous is a very fit one, because coal consists principally of carbon; not entirely, however, for analysis shows that it contains also some hydrogen, a little nitrogen, oxygen, a small proportion of sulphur, and a mixture of mineral substances, consisting principally of silica, alumina, and peroxide of iron, which are left after the combustion of the coal, in the form of ash.

The natural history and geology of the coal formations are of great theoretical and practical interest. Their age must be very great, as there have never been found in them any human traces, from which it must be inferred that man did not then exist. The principal animal forms are of a much

lower type, consisting of fresh-water shells, reptilian fishes, and crustacea; while the vegetation of that epoch was of a kind generally different from that of our own, and finding representatives only in tropical regions. The impressions they have left, and the skeletons of them which remain, show that they were of a similar character to what we now know as horse-tails, pines resembling the araucaria of our gardens, ferns, club mosses, and a sort of palm; these were all of great size. The ferns, which, as we know them, are never more than a few feet high, were then branched, and had a height of 50 feet; and the club mosses, very insignificant in our age and country, were 60 or 70 feet high. Taking into consideration the gigantic dimensions of these different plants and the branched character of the ferns, such as at the present day exist only in very hot climates, we are led to conclude that in our own and other countries where the climate is temperate, it must then have been tropical. Hutton discovered the most decisive and indisputable proof of the vegetable origin of even the most bituminous coal; he has ascertained that if any of the varieties of coal found near Newcastle be cut into very thin slices, and submitted to the microscope, more or less of vegetable structure can be recognised. He says: "Each of these three kinds of coal, besides the fine distinct reticulation of the original vegetable texture, exhibits other cells, which are filled with a light wine-yellow-coloured matter, apparently of a bituminous nature, and which is so volatile as to be entirely expelled by heat before any change is effected in the other constituents of the coal."

A period when such rapidly-growing and enormous plants, of unlimited number, existed, is thus seen to have been highly favourable to the formation of those immense stores of vegetable matter which, however collected together into beds —whether, as some suppose, in a manner similar to the

formation of peat beds, as we now observe them, or by being transported from the place of their growth by the agency of rival currents, as is seen to be the case to a large extent in the American rivers of the present day, or by both of these means—form the deposits of coal which are of so much value and importance to us at the present day. There can be no doubt that coal is derived from this source—that it is merely changed wood, such change being doubtless effected by the combined effects of moisture, heat, and pressure. We know the chemical composition of wood as well as of coal, and it is quite easy to account for the changes which occur to transform the one into the other. Before tracing the changes, however, let us glance at the different varieties of coal, the simplest division of which is into lignite, bituminous coal, and anthracite. The first presents us with an example of the least carbonised wood, and the last an example of the most carbonised, the bituminous being intermediate. We have similar degrees of change in a peat-bog, where may be found woody matter, scarcely changed at all, and, in a lower position, woody matter, black, carbonised and closely resembling ordinary coal.

The table shews at a glance the comparative composition of the three varieties of coal referred to :—

	Lignite.	Bituminous Coal.	Anthracite.
Carbon	66·32	78·57	90·39
Hydrogen	5·63	5.29	3·28
Nitrogen	0·56	1.84	0·83
Oxygen	22·86	12·88	2·98
Sulphur	2·36	0·39	0·91
Ash	2·27	1·03	1·61
	100·00	100·00	100·00

Every element and constituent nearly is seen to be dimi-

nished in the transformation of lignite into anthracite, except the element carbon, which progressively increases; and the same facts may be seen to obtain in a more extended manner in the next table, which traces the chemical changes from wood through the different varieties of coal to anthracite, omitting the ash:—

Composition per Cent., without Ash.

Description of Fuel.	Carbon.	Hydrogen.	Nitrogen and Oxygen.
Woody fibre ...	52·65	5·25	42·10
Peat.....	60·02	5·88	34·10
Lignite	66·96	5·25	27·76
Earthy coal.....	74·20	5·89	19·90
Wigan Cannel...	85·81	5·85	8·34
Newcastle	88·42	5·61	5·97
Anthracite	94·05	3·38	2·57

The chemical composition of these different combustibles being known, we may now consider the nature of the chemical changes which they have undergone. The nitrogen being very small in quantity, averaging only about one per cent., we may omit it from our scheme, and look upon wood as consisting of the three elements, carbon, hydrogen, and oxygen. As soon as a plant dies, it begins to decay, in which very gradual process, the three elements enter into new combinations to form compounds which did not exist in the living wood. One part of the carbon enters into combination with part of the oxygen to form carbonic acid: another part combines with some of the hydrogen to form carburetted hydrogen, or fire damp; while the remaining carbon, having no more oxygen or hydrogen to combine with, being in fact in excess, remains, and constitutes the black coal. If there were enough oxygen and hydrogen in the wood to combine with all the carbon, probably it would have been entirely removed by the same process, and there would have been no carbonaceous

residue; in other words, no coal measures. The whole of the oxygen and of the hydrogen does not respectively combine with the carbon; portions of them combine together, and form water; so that the three compounds resulting from the slow decay of wood are carbonic acid, water, and carburetted hydrogen.

Wood, indeed, may be regarded as carbon and water, inasmuch as water is composed of hydrogen and oxygen. If we could extract the water, we might expect the carbon to remain. Such is the case. If I place sulphuric acid in contact with wood, it abstracts the water, for which it has a remarkably powerful attraction, and black carbon remains. *(Wood was here submitted to the action of sulphuric acid, and a black carbonaceous residue was left.)*

The same phenomenon occurs in the case of sugar, which has much the same chemical constitution as wood.

You see what a black swollen mass of light charcoal is left as the result of abstracting the water. *(Experiment.)*

In looking at the diagrams, we perceive that these changes have taken place to a less extent in lignite, or brown coal, than in the more perfect kinds of coal. The former contains proportionately less carbon and more hydrogen and oxygen, and it is further probable that decomposition has advanced less, from the circumstance of the lignite being more recent than coal, a very lengthened period of time being necessary for the perfection of the chemical changes. This view is confirmed by the geological position of the two substances, for while coal is found situated between the Old and New Red Sandstones, belonging to what is known as the period of ancient life—Palæozic period—the lignite occurs in the later times, when the Oolite, and beds of the Tertiary System were formed, classed by geologists in the periods of middle and recent life respectively—Mesozoic and Cainozoic periods.

Anthracite is the species of coal in which the changes have advanced farthest. It is the most completely carbonised, and in consequence of its containing so little hydrogen, it burns without flame, which renders it useless for fuel in ordinary fire-places, but very valuable as a powerful fuel for use in furnaces, where it can be urged by means of a strong draught.

We can now understand, not only how coal has been formed, but also how carburetted hydrogen, the dangerous fire-damp, has been generated, and confined in fissures or pores in the coal where there has been no outlet for its escape into the air. Fortunately, it is not accumulated in all coal measures, but where it is, as in the North of England, it is liberated from its high-pressure prison by the pick of the miner, and forms those jets of inflammable gas, called "blowers," which are so dangerous to the miner, and against which he should always be diligently on his guard.

The position of coal beds with respect to the earth's surface varies very much, for although coal belongs to that portion of the earth's crust which was deposited countless ages ago, yet, owing to various convulsions of nature, causing upheavals and displacements, it is found at almost all elevations, from 8,000 feet above the level of the sea, to 1,800 feet below it, as at Whitehaven, where, in addition to its depth, it is worked under the bed of the ocean for nearly a mile. It is, therefore, nearly certain that there are immense stores of coal existing at depths, and in positions, which render them entirely inaccessible to the miner, and so lost to mankind.

Carbon forms two important oxides by union with oxygen, which are called respectively carbonic oxide and carbonic acid. The first contains only half the quantity of oxygen which is contained in the second, and its properties, consequently, considerably differ from those of the latter compound.

Carbonic oxide is lighter than air, 0.969, air being unity. It is only slightly soluble in water. It is combustible, burning with a blue flame, and this peculiar lambent blue flame you must all of you have seen playing over the surface—the *upper* surface—of very *well-burnt* fires. Here is the gas, and on applying to it a light, you will observe its combustibility. *(The gas was burnt, with its characteristic blue flame.)*

You recognise here the same kind of flame which is seen on hot fires, except that it is more blue, owing to the absence of the background of red-hot fuel, and it is prepared in the laboratory for experiment in a similar manner to that by which it is produced in common fires. In the laboratory, we fill a porcelain tube with pieces of charcoal (carbon), heat the tube very hot in a suitable furnace, and pass carbonic acid gas through the tube. The gas which escapes from the tube, however, is not carbonic acid, but carbonic oxide. Now, the same conditions exist in a common fire, as I will explain. The oxygen of the air rushing into the fire, at the bottom of the grate, combines with the heated coal (carbon), and forms carbonic acid (CO_2). As this carbonic acid ascends on its way to the chimney, through the very hot well-burnt fuel, it undergoes decomposition. Half the oxygen which the carbon had combined with when it formed carbonic acid, is given up to the hot coal, and out of one molecule of carbonic acid gas and one atom of carbon, are formed two molecules of carbonic oxide (C O), which, on arriving at the upper surface of the fire, and finding there plenty of oxygen, burns with the blue flame in question, and is brought again, by this means, to carbonic acid (CO_2.)

Carbonic oxide is extremely poisonous, very much more so than carbonic acid. It is produced when carbon burns with an insufficient supply of air.

The gas has never been liquified.

Carbonic acid, known to the miner as "choke-damp," or "after-damp," is produced when carbon is burned with a sufficient supply of air, or of oxygen. It presents some characters in common with carbonic oxide, but many widely differing from it; for instance, it is a heavy gas, half as heavy again as air, while carbonic oxide is lighter than air. I will prepare some carbonic acid gas, and we shall then be able to examine its most striking characters. Limestone, marble, chalk, &c., consist of this gas combined with lime. On adding a strong acid, the lime is seized by it, and the carbonic acid is liberated, not in the solid form, as it existed in the carbonate of lime, but in the form of gas, which we may conveniently collect over water. I will, however, first prepare a little by burning carbon in pure oxygen. *(The gas was here prepared.)*

We see at once that, like all the other gases which have come under our notice, it is colourless and invisible, but, unlike carbonic oxide, it is very soluble in water, as is shown by its being used for imparting effervescence to soda water, lemonade, &c. Besides its solubility, it has many interesting characters; but those of the greatest interest to us are its weight, and its effect on animal life.

Whenever a gas will not support the burning of an ordinary combustible, it will not support life. Without, therefore, introducing a small animal into the gas, which is sometimes done, we may test its power of supporting life or not, by immersing a lighted candle in it. *(The candle was plunged into the gas).*

You see it is immediately extinguished. Any animal surrounded by the gas would have its life extinguished in precisely the same manner. It would be suffocated, or "choked." Hence the term "choke-damp," which is applied to it, for it is the suffocating gas which fills the mine after an explosion

of fire-damp, as I shall more fully explain in my next lecture.

A candle, then, becomes a good test for the presence of this deadly gas, and it is the one used by miners and well sinkers to ascertain whether the air of a well, pit, or working, is fit to support their lives. Sometimes when, through carelessness or thoughtlessness, this test is neglected, men descend into places where they are rendered insensible, and others, who go to their assistance, share the same fate, and all are sacrificed; for, unfortunately, uneducated men are apt to disregard a danger which they cannot see.

Carbonic acid gas is produced from a variety of sources, and is therefore constantly being introduced into the atmosphere. The burning of all ordinary combustibles yields it, for as they consist essentially of carbon and hydrogen, their combustion or oxidation produces carbonic acid by the oxidation of the carbon, and water by the oxidation of the hydrogen. If I pass atmospheric oxygen through lime water, it is a long time in turning turbid; but if I pass through it the gases resulting from a candle, gas flame, or fire, you will see the turbidity occurs immediately. *(Experiment).*

The respiration of animals is another abundant source of carbonic acid. On breathing through our old test, lime water, you observe how immediately the presence of carbonic acid is shown. *(Air was drawn through one bottle, and breath was forced through another).*

Besides these processes, those of fermentation, decay, and others employed in the arts, tend to increase the amount of this gas, which is poured into the atmosphere.

The gas is so heavy that it can be poured like water from one vessel into another, and we will employ, as a test of its transference, the burning candle.

We might employ lime water to illustrate the transference of the gas. *(The gas was poured from one vessel to another upon a candle. A little lime water was placed in the same glass.)* You observe that the candle is extinguished, and that the lime water has become milky.

These two properties of carbonic acid have important practical bearings upon the subject of mining, which I shall have to dwell upon more at length in my next and last lecture.

We have seen how the gas is produced by the burning of carbon in oxygen, during which they combine to form this invisible compound, and it may be interesting to you to have proof that solid, black carbon is contained in it beyond that afforded by the synthetical experiment. I will therefore illustrate to you analytically the same fact. By passing a stream of carbonic acid gas over heated potassium, the latter will, by virtue of its superior chemical attraction, seize the oxygen of the gas, and the carbon will at the same time be liberated as a solid black powder. *(This experiment was performed).* Carbonic acid can, by cold and pressure, be not only liquefied but solidified.

Hydrogen had long been known to chemists in an impure state, but it was Cavendish who, in 1776, first examined it unmixed with other gases, with some of which it had previously been confounded, and which were all called Inflammable Air. It is an ingredient of minerals, vegetables, and animals, and being found in all vegetables, it is not surprising that it should form a constituent part of coal. It forms one ninth of water, so that it is a very abundant element, and when required for experimental or other purposes, it is always obtained from water. For the illustration of its properties, I will prepare it from that fluid by means of zinc and sulphuric acid. *(The gas was prepared, and collected into gas jars).*

And now, having collected sufficient, let us glance at its properties. It is a highly inflammable gas, combining with oxygen, when its temperature is raised, and burning with intense heat; with more heat, in fact, than any other combustible, the reason of which is, that in burning it combines with more oxygen than does any other combustible. *(The gas was lighted).*

The flame, though intensely hot, is, however, almost invisible, the reason of which I shall explain presently. Let us be content at present to observe its combustibility. Having done that, let us ascertain if it be a supporter of combustion, for which purpose I introduce a lighted taper into a a jar of the gas. *(Experiment.)* You will observe it is immediately extinguished.

Here then is a great difference, apparently, between oxygen and this gas, for oxygen did not burn, while it "supported" combustion with the most intense energy.

The difference in respect of combustibility is, however, more apparent than real. Oxygen cannot burn in air because it has no affinity scarcely for nitrogen, and it cannot combine with itself; hydrogen burns in the air because it has a great disposition to unite with oxygen, and it is the energy of this chemical combination which determines the development of heat and light. Hydrogen would not burn in an atmosphere of the same gas, any more than oxygen will burn in oxygen, but it would not be reasonable therefore to say that hydrogen is not combustible. *(It was here shown that a jet of hydrogen would not burn in hydrogen).* But it is no more reasonable to say that oxygen is only a supporter of combustion and not a combustible, for if we place a jet of oxygen in favourable conditions, it will burn as readily as hydrogen; for instance, if I raise the temperature of a jet of oxygen in an atmosphere of hydrogen, the oxygen will burn just as unmistakeably as a

jet of hydrogen does in an atmosphere of oxygen. *(A jet of oxygen was burnt in an atmosphere of hydrogen.)* So that whether we have a jet of hydrogen in oxygen, or a jet of oxygen in hydrogen, the result is the same—heat and light. In both cases there is the same appearance of a burning jet, because the combustion can go on only where the two gases meet; in the one case oxygen surrounds the issuing hydrogen, in the other the hydrogen surrounds the issuing oxygen, and union can take place only where they touch, or at the outside of the jet, in either case.

These actions are particularly interesting, as proving that flame—in other words, heat and light—is merely the result of energetic chemical union, and has no relation to the artificially classified groups of combustibles and supporters of combustion, as distinct in chemical properties. What is the result of this energetic union between oxygen and hydrogen? What compound is produced by this union attended with fire? One would be almost led to speculate that it must be some remarkable compound of an active chemical, possibly explosive, character, whereas we find that it is simply water. *(This was shown by burning a jet of hydrogen in air, and condensing the product.)* This fact was first demonstrated by Cavendish. Whenever any ordinary combustible hydro-carbon burns, then, water is one of the products.

We may very properly consider here the nature of the difference between combustion, in the ordinary sense of the term, and explosion. Chemically, they are one and the same action, physically there is a wide difference. They involve differences of degree only, not of kind. In combustion, as when a jet of common gas burns, the union is gradual, the combustible gas burning as fast as it issues from the jet and comes into contact with the oxygen of the air, but not burning in the gas pipe because there is no oxygen in the pipe for it to com-

bine with. In explosions, however, the combustible gas is mixed thoroughly, intimately with the air, and when union takes place it does so instantaneously, throughout the entire volume of gas, producing one great sheet of flame, an intense heat widely distributed, enormous expansion and contraction, and consequently great disruptive and destructive force. You have seen how quickly a bottle full of hydrogen burns when admitted into the air through a jet; let us see how the same gas will burn when mixed all at once with the oxygen necessary to combine with it. *(A jar of the mixed gases was ignited, with sudden and loud explosion.)*

A still juster idea is to be formed of the immense force locked up in these simple gases, by blowing a few soap bubbles with the same mixture, and inflaming them. *(The experiment was performed.)*

Here you have a flash of light, a report like that of a gun, and a concussion which frequently breaks the vessel containing the mixture, even on this small scale; and the wonderful result of this remarkable development of chemical action is a little pure water, one of the principal properties of which is to extinguish flame.

Besides the inflammability of hydrogen, we have another striking peculiarity in its extreme lightness. Indeed, it is the lightest body in nature; it is 16 times lighter than oxygen, and not quite $14\frac{1}{2}$ times lighter than atmospheric air. It is therefore conveniently adopted as the standard of specific weight of gases. It instantly escapes from an open vessel in which it may be generated, unless the vessel be inverted, and this is why I held the jar of gas upside down when I was illustrating its combustibility, and its inability to support the burning of a taper. If, then, we wish to transfer this gas from one vessel to another in the air, we must do so by pouring it upwards; just as we transfer gases upwards in heavier

water, so hydrogen is poured upwards in the heavier air. *(The gas was thus transferred, and its change of place illustrated.)*

It was formerly used for inflating balloons, but coal gas is now used, though much heavier, on account of its greater cheapness and convenience.

Owing to the inflammability of hydrogen itself, it need hardly surprise us that its compounds with other combustible substances are inflammable also. The most striking of these, perhaps, is the compound of hydrogen and phosphorus known as "Ignis Fatuus," "Will o' the Wisp," and "Jack o' Lantern," and which is characterised by so strong an affinity for oxygen that it takes fire the moment it comes into contact with it. I will generate a little of the gas—*(the gas was prepared)*—and now you observe the brilliant flash of light which is the result of its entrance into the air, and the singular, expanding, and rotating circles, of white smoke, produced by the combustion.

Hydrogen forms interesting compounds in the gaseous condition by union with carbon, to which I have referred when speaking of the destructive distillation of wood. The same gases are formed as a result of the destructive distillation of coal; they exist in cavities or pores in the coal in mines, in the form of "fire-damp," and they form the essential parts of illuminating gas which we burn, as it is supplied to us from the distillation of coal at the gas works. We have the same phenomena in the burning of a common candle: first the lighting of the wick, by which the tallow is melted, the capillary attraction of the melted tallow up the tubes or pores of the wick, and then the actual destructive distillation of the melted tallow by the heat of the burning wick. The result is the conversion of the tallow into gaseous compounds of hydrogen and carbon, which in burning constitute the candle flame.

It will not be unprofitable for us to consider at a little length the chemical and physical phenomena pertaining to the combustion of a candle. If the candle flame be carefully examined, it will be observed to consist of three distinct parts, conical in form. First, immediately surrounding the wick, is seen a dark part. Secondly, around this, the greater and luminous portion of the flame; and thirdly, a very narrow and scarcely visible purplish envelope forming the exterior portion.

In the central area are the gaseous hydro-carbons produced by the destructive distillation of the tallow, and as they are surrounded by envelopes of burning gas they cannot at once themselves be burnt, so that there is no combustion in the core ofa candle flame; or, in other words, the flame is *hollow.* This is readily proved by depressing for a very short time a piece of paper upon the flame. The paper will be burnt in the form of a circle; that is, only by the outside of the flame. *(This was done).* Or we may press a piece of wire gauze down upon the flame when it will be clearly *seen* that there is no combustion in the central part. *(Experiment.)*

This central part in which there is no flame is really composed of gaseous hydro-carbons, the result of the distillation of the melted tallow in the pores of the burning wick. That such is the case may be proved by conducting the gas from out of the interior of the flame to a distance by means of a tube, and there burning it. *(Experiment.)*

The structure of flame is complex, varying in the different parts. We have seen that in the interior there is unburnt gas; besides this internal cone there are two external cones, the middle one, which forms the luminous part of the flame, consisting of burnt hydrogen, in which the solid particles of carbon separated from the gaseous hydro-carbons are made white hot, while in the external cone these carbon particles

are themselves supplied with sufficient atmospheric oxygen to enable them to burn to carbonic acid. The hydrogen burns first in consequence of its more powerful affinities: the results of the complete combustion are carbonic acid gas and water. These facts are well illustrated by depressing a card into the different parts of a flame. If depressed into the gaseous cone it is scarcely affected; if depressed into the middle or luminous cone, it is intensely blackened by a deposition of the unburnt carbon; if held in the outer cone, where the carbon has undergone complete combustion, there is no blackening whatever. *(This was illustrated by means of a card).*

The same thing is shown by syphoning off the vapours from the different parts of the flame. The inner cone furnishes white vapours of hydro-carbons which are combustible; the middle cone yields black carbon and water; the outer cone supplies carbonic acid, as is shown by its action on lime water.

This subject, though full of interest and pregnant of chemical and philosophical facts, is too extensive to be pursued farther here; its connection with our subject, however, is so natural that I have thought it desirable so far to explain and illustrate it.

It now remains for us to devote a few minutes to the element sulphur.

Sulphur is the last element which claims our attention, and though it is a substance of immense interest, both in a chemical and general point of view, yet is possesses only a very limited interest in its connection with the Chemistry of the Mine.

It is true it forms a part of coal, but it is only a very small part, averaging only about one per cent, and affecting the consumer of coal much more than the miner; being objectionable particularly to the smelter of iron and other metals, and

to the gas manufacturers; objectionable also in its effects on steam boilers and the like, besides burning in ordinary fire-places to an irritating gas, sulphurous acid, which becomes an injurious ingrediment of the atmosphere. It is particularly fatal to vegetation, and you cannot have failed to observe how soon trees become blasted, and disappear, in the neighbourhood of lime-kilns, brick-kilns, coke hearths, and wherever large quantities of coal are being consumed. Sometimes coal is found containing a larger quantity of sulphur, so much indeed as to give an offensive smell in burning. Such coal, though it burns well, cannot be used as house-fuel. We have some of it, I believe, in the Staffordshire coal field, called the New Mine coal, and *Stinking coal.*

The form in which sulphur occurs in coal principally, is as sulphide of iron, commonly called pyrites. It is seen upon the recently fractured surface of coal in very thin but bright layers having precisely the appearance of brass, and often mistaken in the gold diggings for gold. It has probably derived its origin, from the abstraction of oxygen, from sulphates.

It has been stated that the sulphur in coal is the cause of spontaneous combustion—"fire-stink." My remarks upon the action of the finely divided carbon of coal negative this view respecting which I shall have more to say in my next lecture.

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LECTURE III.

GENTLEMEN,

The knowledge we have already obtained of the elements carbon and hydrogen, will enable us, with advantage, to enter upon the study of the nature and properties of that interesting and important compound of the two, variously and synonymously called *light carburetted hydrogen* gas, *marsh gas*, and *fire-damp*, or *pit gas*.

The name carburetted hydrogen at once explains its constitution; the name marsh gas indicates that it is evolved from marshy lands; and the term fire-damp, or fire gas, is that by which the miner designates it, from his unfortunate knowledge, or experience, that it takes fire under certain circumstances.

The formation of this gas in marshes, enables us readily to understand its production in coal beds. It proceeds from the decomposition of vegetable matter in damp and watery places, and as all coal consists of vegetable matter, the origin of the gas, if not the condition under which it is produced, in both cases, is precisely similar; it is possible, however, that a higher temperature may have been concerned in the production of fire-damp, than in that of marsh gas, which is produced at common temperatures, in presence of much moisture.

Marsh gas can readily be collected, by holding a bottle full of water, mouth downwards, in the water of a stagnant pool which has decayed leaves on the bottom; by stirring up the mud with a stick, the gas is disengaged, and ascends in bubbles. It is not pure carburetted hydrogen, but is easily deprived of the carbonic acid with which it is mixed.

For experimental purposes, however, the gas is not obtained from marshes, from coal mines, or from common coal gas, of which it forms a very large part—about 40 per cent.—but from a salt of acetic acid. Acetic acid is a compound organic acid, containing, like wood, carbon, hydrogen and oxygen, and when a salt of it is heated to destructive distillation, it splits up just as wood does, and yields carburetted hydrogen and carbonic acid. I have here ready bottles of the gas, partly to save time in preparation, and partly because of the difficulty of preparing it on the lecture table; but before proceeding to examine its properties, I wish you again to see that the decomposition of wood is attended with the production of a combustible gas. *(Wood was here distilled.)*

The gas which you see burning is analogous to fire-damp in its origin and composition, and you see there is formed besides it, water, tar, pyroligneous acid, &c. No doubt the immense stores of petrolene, pitch, asphalt, etc., which are found in both the old and new worlds, have proceeded from the destructive distillation of the masses of wood and coal which exist there, having been subjected, among other influences, to that of a high temperature.

Marsh gas, though containing black carbon, is as transparent and colourless as though it contained only hydrogen; and, like that gas, has neither taste nor smell.

It is combustible like hydrogen, and gives scarcely more light, burning with a pale, scarcely luminous, blueish-yellow flame, in which respect it differs from all other hydro-carbon.

The fact of its containing carbon, however, may be illustrated by separating the hydrogen from it, when it will be left in its well known solid form, as black as if obtained from wood or bone.

Chlorine is a substance which has a strong disposition to combine with hydrogen, so strong, indeed, that if we mix carburetted hydrogen with it and raise the temperature of the mixture, the chlorine will seize the hydrogen with the formation of hydrochloric acid, and the carbon will be left *(This experiment was performed, and a black cloud of finely divided carbon was left.)*

This experiment furnishes another striking illustration of the fact that when elements unite chemically to form a compound, they lose their individual properties, and produce a compound which has nothing, frequently, in common with its constituents. But for this proof of the compound nature of carburetted hydrogen it might readily be mistaken by a cursory observer for the element hydrogen, which it resembles in many respects. They are both combustible; they both burn with a slightly luminous flame, though carburetted hydrogen does yield *some* light in burning; and they neither of them support combustion. There is, in fact, no distinctive test for the gas; so that in order to identify it, it has to be analytically examined.

I will now burn the gas *(this was done)*, and you observe how feebly luminous is the flame. You remember that when I burnt carbon in oxygen and in air, carbonic acid gas was formed; and that when hydrogen was burnt in air water was formed. You will no doubt anticipate the statement, therefore, that when carburetted hydrogen is burnt, containing as it does both carbon and hydrogen, both carbonic acid and water are produced. It is important that you should fully realise these facts, as they have an important bearing on fire-damp explo-

sions. I will, therefore, illustrate them by burning a jet of the gas and collecting the products. *(The experiment was performed; the carbonic acid was collected and tested with lime water; the water was condensed.)*

You observe that the interior of the glass held over the jet is bedewed with moisture; and on testing the product of combustion with lime-water, you recognise the presence of carbonic acid.

The combustion of carburetted hydrogen, then, is a safe and simple process when it is effected gradually, but just as the combustion was sudden and explosive when hydrogen and oxygen were thoroughly mixed and ignited, so, if we ignite a mixture of carburetted hydrogen and oxygen, and inflame the mixture, they suddenly unite with a loud and violent explosion, the force of which is calculated to equal a pressure of 555lbs. on the square inch. *(A mixture of the two gases was here exploded.)*

Now, a similar result follows the application of a light to a mixture of the gas with air. As air, however, contains only two volumes of oxygen, the quantity required, in ten, we must add ten volumes of it to our one of the gas, in order to supply the necessary amount of oxygen to combine with it; but in consequence of the dilution of the oxygen with eight parts inert nitrogen, the explosion is more feeble. Comparatively weak as this explosion is, it is nevertheless absolutely very powerful, being calculated to exert a pressure of 210 pounds on the square inch—amply sufficient to account for the destructive violence of coal mine explosions.

Fire-damp, then, explodes when mixed with either oxygen or air, and a light is applied, but it does not do so in all proportions. The most favourable proportions for explosion are, one volume of fire-damp to eight or ten of air; but when the volume of air is either very small or very great, no explosion

occurs. Where the air amounts to seventeen times the volume of the gas, this is the case, the large volume of air conducting the heat away and preventing its rising high enough; while, on the contrary, if the proportion of air is less than four times that of the gas, the quantity of oxygen is insufficient to burn it.

One of the names of the hydro-carbon which we are considering is *light* carburetted hydrogen; properly so designated for two reasons. In the first place, there is another gaseous hydro-carbon containing twice as much carbon, and therefore comparatively heavy, and for the sake of distinction called *heavy* carburetted hydrogen; and in the second place, light carburetted hydrogen is only about half as heavy as air, or only eight times as heavy as hydrogen, whereas oxygen is 16 times as heavy as hydrogen, and air is $14\frac{1}{2}$ times as heavy; and therefore when compared with all ordinary gases, save hydrogen, it is emphatically *light*. It is lighter than all the gases except hydrogen; hence it is used now largely (as an ingredient of coal gas) for inflating the balloons of the aëronaut, where formerly the more expensive and troublesome hydrogen was employed. I have here a small balloon inflated with this light compound gas, and you observe how great is its levity, ascending in the air, and rapidly passing up through it, as a cork would ascend in water, and so it continues to rise until it encounters some obstacle, such as the roof, or ceiling. *(A balloon inflated with carburetted hydrogen was allowed to ascend to the ceiling.)*

It is the great lightness of this gas, compared with atmospheric air, which causes it to occupy the highest place in mine workings, where it collects more than in any other part, and where it may be lighted with impunity when it exists only in *small* quantity. I have heard of workings where, by holding a lighted candle for a moment near the

roof, there will be a slight explosion, and by then holding it near the floor the light will be extinguished; the extinction being caused by carbonic acid gas, which being half as heavy again as air, occupies the lowest place.

Among the numerous synonyms of carburetted hydrogen I did not include one very commonly used among miners, viz., *Sulphur*. It is not sulphur, and it contains no sulphur, and therefore it is as inappropriate to call it so, as it is to call "black lead," a substance which contains no lead, but consists of carbon; and copperas, a salt which contains no copper, but the metal iron. This term, sulphur, applied to fire-damp, is founded altogether on a misconception, and is nothing more than a technical provincialism; such being the case, the sooner the term is abandoned the better. The generic term, "gas," or "pit gas," is a far better one.

The temperature requisite to ignite inflammable gases differs very much, and fire-damp requires a higher temperature than most other gases. This is a very favourable circumstance in connection with the construction of the safety-lamp. A red-hot solid body will not inflame a mixture of fire-damp and oxygen, and this agrees with the fact that in making explorations of an urgent character, in an explosive mixture of fire-damp and air, the Davy lamp may be continued to be used even when red-hot. Of course, this should never be done, except in cases of the most pressing necessity, as, for instance, in the attempt to rescue life when placed in imminent danger. But though a red-hot body will not ignite a mixture of fire-damp and air, it will ignite a mixture of hydrogen and oxygen. *(A red-hot bar was introduced into vessels of the two mixtures referred to, with the results stated.)*

Flame, however, will ignite the former, as you see. *(The mixture of fire-damp and air which was not ignited by the red-hot bar, was here shown to be exploded by a body burning with flame.)*

But even flame must be allowed to remain in contact with the mixed gases a certain time, in order to heat them to a definite point, without which no explosion will occur; and on this principle was constructed the original safety-lamp of Stephenson.

In this lamp the flame was surrounded by a tall glass chimney, the rapid draught through which, did not allow the combustible mixture to remain long enough in contact with the flame to become heated as high as the point of ignition. This fact admits of illustration; in this funnel I have a mixture of fire-damp and air in proper proportions for explosion, on forcing the gaseous mixture through the aperture in a *rapid* stream, it will not take fire when a burning taper is held in it; but on allowing the gases to escape slowly, and thus giving them time to be sufficiently heated by contact with the flame, an explosion takes place. *(Experiment.)*

In order to provide a preventive of coal mine explosions, Sir Humphrey Davy was called upon; and his great genius was, perhaps, never rendered more evident than when, in response to a direct request, he applied his mind to the subject, and achieved the construction of his well-known safety-lamp. Great results are almost always obtained by simple means, and the safety-lamp is no exception, the principle of its construction being simplicity itself.

The principle is, that flame is extinguished when its temperature is lowered to a certain extent. In "blowing out" a candle, the extinction, is produced, principally, by the excessive supply of air cooling the flame below the temperature at which it can burn; burning coals are readily extinguished, if taken from a fire, and placed separately on good conductors, such as iron, &c., and it is upon this property of metals as good conductors, that Davy relied in the construction of his lamp.

That metals are good conductors is readily shown. If we heat one end of a rod of metal, the other end will soon become hot, in whatever position it be placed; the heat is said to be conducted along it. Now, if heat be conducted along the bar, the bar must first receive the heat from something which to that extent must be cooled. This is well seen by using, instead of a bar, a coil of metal, by which the source of heat can be entirely surrounded by the conductor, and the heat the more rapidly absorbed and conducted away.

If I depress this little coil of copper wire upon the flame of a candle, you will observe that the flame does not burn within the coil, although there is apparently plenty of room for it; and if it be depressed until it surrounds the wick, you will see that the flame becomes entirely extinguished, the heat necessary for its existence being conducted away into the wire. The heat does not reach my hand and burn me, because the wire being long, the surrounding air conducts the heat from it, and so exerts a cooling effect upon it. That the extinction of the candle flame is due to the cooling effect of the copper is shown by making the copper very hot; if it could be made quite as hot as the flame, it would not cool it at all, but when made nearly as hot, it fails to cool it sufficiently to extinguish it. *(The red-hot coil was shown not to extinguish the flame.)*

A round *tube* of copper would answer the purpose as well as the round coil; a square tube would also answer equally well, and the longer the tube, the better it would conduct. Practically, a very large number of very *short* square tubes of exceedingly small diameter, are as effective as longer tubes of greater diameter, and these conditions are fulfilled in what is known as "wire gauze."

The smaller the tubes, the better the conducting surface, 700 or 800 meshes in the square inch answer well. If such a

piece of gauze be depressed on a gas flame, it nearly extinguishes it, and the flame will not pass through it; or if I allow the unlighted gas to pass through it, the gas may be lighted above the gauze, without the flame communicating with the part of the jet which is beneath the gauze.

Even burning spirit, when poured upon the gauze, will be extinguished, the spirit passing through, the flame being unable to accompany it. *(All these facts were experimentally illustrated.)*

Now it is upon the simple principle which these facts illustrate, that Davy constructed his safety-lamp, which, with care, forms a perfect protection to the miner in his dangerous employment; and is, therefore, justly deserving of its title. In speaking of the beautiful simplicity and efficiency of the Davy safety-lamp, a writer has said, "There may be seen the enemy in harmless coruscations, shorn of its strength, and imprisoned in a slender cage, which the wand of science has encircled around the angel of death."

It is nothing more than an oil lamp, surrounded with a cage of iron wire gauze, just such as I have experimented with. Here is one of them, which however, it is unnecessary for me to exhibit to an audience of miners, though fortunately it is not much seen, because not required, in our Staffordshire coal field, and I sincerely trust that its use may continue to be unnecessary.

When this lamp,while burning, is brought into an explosive mixture of fire-damp and air, the mixture passes into the interior of the lamp, and there it burns, but the flame cannot pass out of the cage to ignite the explosive atmosphere in the pit, because it is so cooled by contact with the gauze as to be extinguished.

If I introduce the lamp into a vessel of air, which shall represent a pit, you will see that the lamp continues to burn

as usual; but on admitting coal gas, which will serve for fire-damp, you will see that the flame of the lamp will flicker and elongate itself, in search of oxygen with which to burn, and will at last be extinguished; while the explosive mixture of fire-damp and air will continue to burn within the cage.

When this appearance occurs in a working, of course the miners should at once accept the simple but infallible warning, and withdraw; because in time the wire gauze would become so hot as to incur the risk of igniting the surrounding fire-damp, and cause that very accident which it is its function to prevent.

Miners object to the use of the lamp because it gives but little light, and the objection certainly does hold; but there are many modifications of the lamp by which this defect is obviated, principally by the introduction of glass into the cage, in front of or around the flame. Through the kindness of your secretary, Mr. Johnson, I am able to exhibit to you some of the principal modifications in question, and for which patents have been taken out; but in all of them the principle of the original invention of Davy remains unaffected, and its great merit is the more widely proclaimed.

In many cases the Davy lamp is used merely as a test of the safety of the air of a working, and is not used as a means of illumination; in this case naked candles are used for affording light, but before the miners commence their work, men are deputed to visit the different parts of the mine, bearing with them the Davy lamp as a test. Naked flames in fiery mines, however, ought never to be used, either ordinarily or in testing for the presence of fire-damp, for the reason that it is impossible to say when "a blower" may be opened by the miner's pick.

Before ventilation was so much practised, a most rude and dangerous method was employed for getting rid of the accu-

mulated fire-damp in mines. Some workman, endowed with more than the usual amount of recklessness, was employed to shut himself up in the mine, in a closet somewhat resembling a large iron safe, and communicating by a small opening with the downcast shaft, by which he could obtain a sufficient supply of air. By means of a string he drew a lighted candle up to the roof, over a pulley fixed for the purpose, when, the moment the candle arrived high enough to come into contact with the explosive gas, which, from its lightness, occupies, as has already been explained, the highest place in the workings, an explosion took place, and the gas was, for the time, got rid of. This, besides its great danger to life and property, was a wretchedly poor expedient, because it gave rise to the production of poisonous carbonic acid gas, which it is as desirable to sweep from the pit as the "damp" itself. This barbarous method was followed by another, the double object of which, was to prevent the ignition of the accumulated gas, and, at the same time, give light to the miner at his work. It involved the use of what was called the steel mill, which is nothing more than a steel disc made to revolve rapidly by means of a multiplying wheel, turned by a boy, and made to throw out a shower of sparks occasionally, by pressing a piece of flint against the revolving disc, when the miner, who worked in total darkness, wished to see how his work was progressing. The light emitted was very little, but, being held close to the excavation, it was sufficient for the purpose of affording a slight view of the work. Besides being a most defective source of light, it was a source of great danger, for if the fire-damp should exist in the mine to such an extent, as to reach as low as the sparks from the mill, an explosion was caused. *(The mill was exhibited and its action shown.)*

It is unfortunate, perhaps, that fire-damp has no odour by which its presence can be detected; when coal gas escapes, it

is instantly recognised by the very strong and disagreeable odour of naphtha, which is one of its constituents, and this characteristic odour serves to warn of danger; but the only indication of fire-damp in the pit, is the blue flame which plays around the candle flame when the "gas" is mixed in small proportion with air. At any moment, however, the quantity of gas may become greater, and increase in proportion, until an explosive mixture is produced.

The difficulty of ascertaining the presence of fire-damp is, however, compensated for, in the circumstance that it is not so prejudical to health as coal gas, for as much as 20 to 30 per cent may be breathed for a short time, without serious inconvenience; if the quantity, however, exceed this amount, it induces symptoms of poisoning, such as headache, vomiting, convulsions, stertorous breathing, dilated pupil.

The gas is constantly breathed in small quantites, and this, apparently, without ill effect; but though this is so, it is by no means certain that the long-continued inhalation of these small quantities is not eventually prejudicial.

Owing to the lightness of fire-damp, its disposition is to collect near the roof of the working, but this disposition is to some extent interfered with by a peculiar property possessed by gases, in consequence of which their particles have a tendency to separate from each other as far as possible; this physical property of gas is known as *diffusion*, and its effect is the intermixture of different gases, when they are in contact.

If we were to take a jar of fire-damp, inverted on account of its lightness, and place its mouth over the mouth of a similar jar containing air, we should find after a time that there was a complete mixture of the two gases; the fire-damp would have descended, in opposition to that other physical force, known as *gravitation*, and the air, equally in opposition

to gravitation, would have ascended; and the result would be that in both jars, there would be an equal admixture of the gases.

The diffusive power of gases is in proportion to the differences of their weights. A light gas diffuses most readily into a heavy gas; or, the greater the difference in weight between two gases, the more rapidly is their mutual diffusion effected. Hydrogen being 14½ times lighter than air, it diffuses very rapidly into it, as is shown by the simple diffusion-tube invented by Graham, who discovered the law of the diffusion of gases. It is simply a glass tube, closed at one end by a plug of plaster of Paris, through the pores of which, the gases are readily able to pass. If I introduce hydrogen into the tube, it will pass out, much more rapidly than the air will pass in; the water will, as a natural consequence, ascend in the tube, and this water will be the measure of the difference of rate of diffusion between hydrogen and atmospheric air.

(The action of diffusion was here shown by means of Graham's diffusion-tube.)

This force of diffusion must, then, operate in diminishing the accumulation of fire-damp. If the fire-damp is given out faster than diffusion can disperse it, it accumulates; if more slowly, accumulation is prevented.

It is common for it to accumulate; and the miner, without knowing much of the philosophy of the question, beats the air with his jacket, or any other convenient article, for the purpose of diffusing it.

Diffusion, then, must be regarded as one of the ways in which danger from fire-damp is obviated.

In rooms, diffusion is found to play an important part in purifying the air; it takes place even through brick and stone walls, particularly when dry, and more rapidly through chinks in walls, doors, and windows.

Roscoe experimentally ascertained that an atmosphere of a room had lost in 90 minutes, from this cause only, half of the quantity of carbonic acid purposely introduced into it. This process, however, is not sufficient of itself to purify the air, even of rooms, still less of mines, and therefore recourse must be had to the more rapid one of ventilation, by which is meant, the admission of a stream of pure air, and the consequent removal of impure air, containing for the most part the exhalations of animals, and the products of combustion.

By the ventilation of mines, the dangerous pit gas, also, is swept out of the working, and displaced by pure air, which is favourable both for combustion and respiration.

It is not known exactly how little carbonic acid is hurtful. The natural quantity in the atmosphere is ·04 per cent., or 4 measures in 10,000. When the quantity reaches 12 measures in 10,000, the air becomes actually offensive, because, not only is carbonic acid present, but also a proportionate quantity of animal impurity, evolved from the skin and lungs. A much less amount of impurity than this, however, is no doubt hurtful if breathed for a long time. Dr. Parkes considers that 6 measures in 10,000 are the maximum amount of permissible impurity.

Dr Angus Smith found that the air of mines, besides being poor in oxygen, contained as much of 78·5 volumns of carbonic acid in 10,000, nearly twenty times the quantity found in fresh air, and 13 times the quantity of permissible impurity set down by Dr. Parkes; and, in addition to this, Dr. Smith found sufficient animal organic matter, to give the smell of *burnt feathers* when the air was burnt.

The ventilation of mines is a matter of the greatest importance, under even the most favourable circumstances; for when you remember that carbonic acid gas, besides being a

constituent of fire-damp itself, is given off in the respiration of men and horses, and is also the product of the combustion of the candles and lamps, and of the explosion of gunpowder in blasting, you will at once understand that the confined space of a working, with its low roof and tortuous windings, is well calculated to harbour these deleterious gases. Even on the surface of the earth, where every habitable spot is comparatively open to the operations of diffusion, and dispersion by winds, and currents of air: houses, &c., may become so foul as to be unfit to support healthy respiration; but in a mine, where there is communication with the air by only one, or at most two, narrow long openings, the shafts, the difficulty, as well as the necessity, of obtaining a plentifuly supply of pure air, is so much the greater.

Carbonic acid, besides being diffused through the air of mines, also frequently accumulates on the ground, and from this circumstance it is not uncommon for persons to have the impression that because the gas is heavier than air, it separates from the lighter gases and falls to the lowest place, just as water would separate from oil. This view, however, is erroneous. The gas so situated is given out from fissures in the rock, or coal, and has never mixed with the air of the mine; for owing to the comparatively small difference of weight between carbonic acid and common air, mutual diffusion is very slow. It does, however, take place in time, and when the mixture is once effected mechanical separation never occurs. If this were not so, it would prove that the force of *gravitation* is more powerful than that of *diffusion*, whereas we have seen that the reverse is the case. The Grotto del Cani, or "Grotto of Dogs," in Italy, is a well marked illustration of carbonic acid being more rapidly emitted from the earth than it can be diffused; so that a person entering the grotto is about knee-deep in the deadly gas, and out of

danger, but on putting a dog on the ground it instantly falls asphyxiated.

This subject is so important, in reference to the health of our miners, that, not only have individuals, but Government has frequently made it a subject of searching inquiry; and in fact is continually, through legal enactment, paying attention to the question, by official inspection.

Let us see what the effect is, on a confined portion of air, when an animal has breathed a portion of it. Before breathing the air, you observe, it supports readily the combustion of a taper.

I will now breathe a part of the air only once, and you will notice that the contents of the jar will no longer support combustion; we know, also, that it is unable to support life.

The effect of the burning of candles, lamps, &c., is equally powerful in vitiating the atmosphere, and rendering it unfit to maintain healthy existence. It is estimated that two ordinary bat-wing burners, each consuming 3 cubic feet of gas per hour, produces as much carbonic acid as the respiration of one man; so that a room containing six persons, and illuminated by six such gas lights, has its air vitiated as much as if it contained nine persons. Under this glass bell-jar I place a taper. After burning a short time it will be extinguished; it has so charged the air with carbonic acid, and deprived it of its oxygen, that it has rendered it unfit to longer support combustion. If I introduce another taper from above, you will see its flame suffer immediate extinction. *(These facts were illustrated.)*

Now, the cause of the extinction of the flame is not the complete removal of the oxygen, for the oxygen still exists in the jar in considerable quantity, but the carbonic acid resulting from the burning candle is mixed to such an extent with the diminished oxygen and the nitrogen, that flame can no

longer burn. The presence of oxygen is shown by the fact that the more energetic combustible, phosphorus, will burn after the candle has been extinguished. *(Experiment.)*

But men and animals are affected by such an atmosphere just as the candle is; they are unable to respire in it, when its oxygen is much diminished, and its proportion of carbonic acid is increased, and long before the whole of the oxygen is removed. Indeed, the animal organisation is more susceptible of the effects of air charged with carbonic acid, than a candle is. If, therefore, a candle burns dimly, but still burns, it is not to be concluded that therefore animal life will be safely maintained in the same medium, but, on the contrary, it must be considered that such an atmosphere is certainly dangerous to animal life, and that no atmosphere is fit to be respired, unless it supports the combustion of a candle with ordinary energy.

In order to purify a deleterious atmosphere, different quantities of air are required, according to circumstances.

In barracks and workshops, about 2,000 cubic feet per head *per hour* are recommended; in schools less is necessary, on account of the occupants being children; in hospitals, under ordinary circumstances, about 3,000 cubic feet are considered necessary; in ordinary mines, 1,400 cubic feet are considered sufficient; when they are charged with much fire-damp, the supply should be increased to 6,000 cubic feet per hour, and it is thought by some that not less than this amount should be supplied in all cases, and that where less is admitted, the energies of the miners suffer a marked diminution.

Horses require about 2,500 cubic feet an hour at the least. All these calculations refer to the smallest quantity of air desirable, but the larger amount of fresh air supplied the better.

The importance of ventilation, in reference to the health of

horses, has been frequently illustrated by the fact, that army horses in stables have experienced a great mortality, while those kept in sheds, even in time of war, have shown a very small rate of mortality. In fact, of all general causes of disease, impure air is the most common and the most dangerous.

The disposition of mines renders it necessary to effect their ventilation by artificial means, the natural agencies of general diffusion and winds, having little influence in the process.

It is generally effected by heat, which is applied at the bottom of a shaft, where there are two—a "downcast" and an "upcast;" but in mines provided with only one shaft, this is divided, and half of it is used for the purpose of maintaining an upward current. It is absolutely necessary that there be two separate passages—for the incoming fresh air, and the outgoing impure air; two currents cannot be effectively maintained through a single passage, any more than an upward and a downward current could be maintained at the same time, in the flue of an ordinary fire-place. This is seen by placing an open lamp chimney, with its lower end resting upon the table, over a burning candle. It is very soon extinguished, because only one opening exists for two currents. *(Experiment.)* If, however, the chimney be raised a little from the table, there are now two available openings—one for the exit of the products of combustion above, and one for the entrance of fresh air from below.

Now, in ventilating a mine, the opening at the bottom of the glass chimney is represented by the downcast shaft, through which the fresh air enters as readily when a fire is lighted at the bottom of the upcast shaft, as if the opening were actually underneath it. The action is well illustrated by this apparatus, where the two lamp chimneys represent the upcast and downcast shafts, and the box below represents the workings of the mine. The burning candle represents, equally, the fire

used in practical ventilation. The candle, you perceive, burns with the ordinary energy as long as both chimneys are open, but if *either* of them be closed the current of air is stopped, as is shown by the effect on the candle, which first burns dimly, then is extinguished; and we thus know that all ventilation is arrested. Under such circumstances, life could be maintained only until the air included in the mine had become vitiated to a degree inconsistent with its maintenance, which in most cases would not be very long. In mines, the current flows through the upcast shaft at the rate of from 8 to 10 cubic feet per second, and it flows through the main galleries at the rate of from 4 to 6 cubic feet per second, except in fire-damp mines, where much more than this is allowed; 150,000 cubic feet of air per hour is passed through some mines.

Great ingenuity has to be exercised to direct the health-bearing current through all the galleries and tortuous windings of a mine, a distance having to be traversed by a portion of air in some mines, of between 30 and 40 miles, before it reaches the upcast shaft.

The size of a shaft varies from 8 to 12 feet in diameter; but supposing it to be 8 feet, its sectional area would, in round numbers, be 50 square feet; and a current of 8 feet per second in the upcast shaft, would give a discharge of 1,440,000 cubic feet per hour, which would give 2,000 cubic feet per hour to 720 men.

The dimensions of the upcast shaft, as regards area and height, are so fixed that there shall be the greatest possible current, without permitting the temperature of the contained air to fall so low, as to be unable to overcome the resistance of the atmosphere, or the action of the winds at the top of the shaft.

Instead of heat, the hydraulic air-pump is used, on the small

scale ,for the ventilation of mines (Struves's Patent). Its construction, and principle of action, may be readily understood by an inspection of the diagram.

Both this machine, however, and the furnace ventilation, in fiery mines, are being gradually superseded by the ventilating fan, which is capable of propelling any quantity of air, through the mine, that may be required.

"Fire-stink," or spontaneous combustion of coal mines, is believed by many to be due to the oxidation of the iron pyrites, or sulphide of iron, which exists to a small extent in coal. A simple exercise of the reasoning faculty would, I think, be sufficient to refute this notion; but if not, it receives its refutation in the well-observed fact, that those descriptions of coal which, contain the least sulphur are more prone to take fire spontaneously, than those which contain the most. I have thought it well just to refer to this point here, but I trust that, in my first lecture, I proved to your satisfaction that the composition of coal, irrespective of the presence of sulphur, is of such a nature as to be highly favourable, when finely divided, to spontaneous combustion.

In order to prevent this spontaneous combustion of small coal, it should not be allowed to *accumulate*; for accumulation confines heat. It should be kept dry, for moisture is another favourable condition ; and above all, a copious supply of air should be allowed to play over it, such as is obtained by that free ventilation, on the importance of which I have already insisted.

The protection afforded by the Davy lamp is, I believe, complete, when it is used in a careful and intelligent manner, but if, through carelessness, a miner allows holes to exist in the gauze, or if he permits it to become bright red-hot, or if, in the recklessness which so commonly attends ignorance, he will persist, contrary to the strictest injunctions, in unscrew-

ing his lamp, for the purpose of obtaining better illumination, or for the more unpardonable one of lighting his pipe, of course the protective properties of the lamp are destroyed.

Davy's safety lamp alone protects only immediately from explosion, and it acts as a warning of the fatal damp; but the great sheet anchor of safety from sudden and shocking death is only to be found in the use of the lamp together with efficient ventilation. It is by the latter that the accumulation of the dangerous air is prevented, or, if it has taken place, that the gas is swept clean out of the workings, or at least prevented collecting to a dangerous extent.

When an explosion occurs, and strikes down the men in the pit, they suffer very much less from burns than from poisoning, by inhaling the after-damp, or carbonic acid. The method which I understand is generally adopted for resuscitation, is to remove a clod from the ground, to place the patient's head in the hole, face downwards, and to put the clod on the back of the head. Nothing could be more unscientific, not to say barbarous. The position of the body is unfavourable, and the air, which is above all things needed, is, as far as possible, excluded.

There should be a free supply of air, bystanders should be prevented pressing closely around, and, above all things, artificial respiration—best with double-action bellows, to pump the poisonous gases out of the lungs, and pure air into them alternately—should be speedily and perseveringly practised. If the surface be cold, the warm bath should be employed, as well as stimulating embrocations to the chest and extremities. As there is congestion of the head, bleeding may be sometimes resorted to with advantage; and stimulants should always be at hand, for administration under medical direction.

There are other things to be attended to, in the manage-

ment of a pit, besides the use of the Davy lamp and the maintenance of free ventilation, the object of which latter is to remove impurity. It is clear that the less impurity the air of a pit contains, the less ventilation will be required ; and therefore, it behoves every miner to attend to his personal habits. The occupation of the miner is always dangerous, and it is comparatively unhealthy ; there is, therefore, the more necessity for his being constantly on his guard, to avoid aggravating the natural disadvantages of his position. The privation of light is an evil more or less great, as shown by the pallor of the countenances of miners. He ought, therefore, when out of the pit to spend as much time as possible in the open air, where as much light, and as much fresh air, as he can command may be obtained ; his occupation being necessarily dusty, and dusty particles being injurious to both the lungs and the skin, he should protect the first by wearing the beard and moustache, and relieve the second by frequent and thorough washing of the whole surface of the body.

Heavy meals in the middle of the day, with large supplies of beer, are to be avoided, a light mid-day meal would be renovating without producing oppression, and the heavier meal would be better postponed until after the termination of the day's work.

Habits of cleanliness should be cultivated, and proper and decent receptacles for excreta should be provided, and used in the workings; and thus the purity of the air would be rendered the greater, and health materially promoted.

Drinking and smoking, stimulating, and therefore agreeable, as they no doubt prove to the tired workman, in combination with the cheery fire and companions of the tavern, are, carried to excess, only calculated still further to depress the physical health. The miner should make his own home his club ; his house and his family should be the centre of his pleasures,

and the scene of his repose; and in this way he would not only derive pleasure and lasting benefit for himself, but, what is equally important, he would dispense them to those around him.

In the event of his having leisure, and desire for self-improvement, he would obtain it by attendance at the reading-rooms, libraries, and lecture-rooms, which are now, happily, to be found in almost every district; he would by these means obtain that information which it is necessary for every individual miner to possess, if we are ever to be rid of the melancholy accidents and fatal explosions, which too often throw whole districts into mourning, and spread sadness through entire communities. I venture to hope that the short course of lectures which I have had the honour to deliver before you, may prove a step in this direction, and help ultimately to conduce to the increased health, happiness, and security of that useful and extensive class, known as our mining population.

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